

ON THE  
VENTS OF HOT VAPOUR

IN  
TUSCANY,

AND THEIR



RELATIONS TO ANCIENT LINES OF FRACTURE  
AND ERUPTION.

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*On the VENTS of HOT VAPOUR in TUSCANY, and their RELATIONS to ANCIENT LINES of FRACTURE and ERUPTION.* By SIR RODERICK IMPEY MURCHISON, G.C.St.S., F.R.S. G.S. L.S., Hon. Mem. R.S. Ed., R.I. Ac., Mem. Imp. Ac. Sc. St. Pet., Corr. Mem. Ac. France, Berlin, Turin, &c. &c.

*Introduction.*—In surveying the principal localities of those remarkable vents of hot vapour in the Tuscan Maremma, called “Lagoni,” “Fumacchi,” “Fumarole,” “Soffioni,” “Mofetti,” and even “Volcani \*,” I perceived that their issue took place upon ancient parallel lines of fracture, along which serpentinous and other eruptive rocks had been emitted. As I am not aware that this coincidence in lines of eruption, acted upon at epochs so remote from each other, has been previously adverted to in any geological account of Tuscany, I will first call attention to the phenomenon. I shall next take this opportunity of expressing my opinion respecting the origin of the “gabbro rosso” of the Tuscans, a rock intimately associated with serpentine; and, after a brief allusion to recent earthquake shocks along the same lines, the memoir will be terminated by glancing at the simultaneous production of great divergent elevations in Italy and in the Alps, after the deposit of the nummulitic eocene formation.

\* For Italian descriptions of the Lagoni, see *Gio. Targioni Tozzetti, Viaggi; Repetti, Dizionario fisico, &c. della Toscana*, tom. iii. p. 369; *Bartolini, Atti dei Fisico-critici*, tom. vi. p. 335; *Mascagni, Commentario* (Siena), 1779; *Guerrazzi, Contin. dei Georgofili*, tom. ii. p. 435; and *Repetti, Dizion. fisic. stor. ec. della Toscana*, tom. ii. p. 624, tom. iii. p. 374, and *Continov. degli Atti dei Georgofili*, tom. xi. p. 49.

*Hot vapour vents.*—If the intensely hot vapour gusts which have issued for centuries from cavities in the rocks of the Tuscan Maremma had been as well known to Dante, as they were to Targioni Tozzetti their graphic describer in the last century, the great poet would surely have selected them as a finer illustration of infernal agency than the feeble “bullicani” of Viterbo\*. In our own day the chief features of the Tuscan escapes of hot gases impregnated with mineral acids have already been described by Mr. Babbage in Murray’s ‘Hand-book of Central Italy,’ and subsequently they have been connected with a geological sketch of other parts of Tuscany by Mr. W. J. Hamilton, Sec. G.S.† In order, however, to render my own view clear, I must offer a slight outline of the chief phenomena.

In addition to other substances, the hot vapours of Tuscany are charged with boracic acid, known only elsewhere in the active volcano of Stromboli. For the extraction of this last-mentioned salt, the extensive works of M. Lardarel have been entered upon at the following nine localities: viz. Lardarello or Monte Cerboli, Lustignano, Monte Rotondo, Sasso, Il Lago, Castel Nuovo, St. Federigo, and St. Ippolito. These places are all situated in that elevated northern portion of the Tuscan Maremma which lies on the left bank of the Cecina. Thence the affluents of that river (the Pavone, Posera, Trossa, and Sterza) flow northwards; whilst the Cornia and its feeder the Melia run down to the Mediterranean in a westerly and southerly direction. The tract, penetrated at intervals by the hot gases, has a length of about eight geographical miles from N.N.W. to S.S.E., and a breadth of about five miles from W.S.W. to E.N.E.; the whole being comprised within  $43^{\circ} 8'$  and  $43^{\circ} 16'$  N. lat.

Subtended generally on the E. and N. by the Cecina, this hilly tract, which is much fissured from N.  $15^{\circ}$  W. to S.  $15^{\circ}$  E., is separated on the east from the deep valley in which that river runs by a lofty ridge extending from Monte Castelli on the N.N.W. to the Gerfalco mountain on the S.S.E.; whilst another but lower ridge parallel to the above, is seen upon the western side of the gaseous district passing from Monte Rufoli to Lustignano, whence it slopes down to the sea-coast between Leghorn and Piombino. The gaseous vents occur therefore in an elevated and broken trough, on lines more or less parallel to the older flanking ridges. The general character and age of the sedimentary deposits of this region have been recently explained by myself‡. It is enough then, for my present purpose, to state, that although the adjacent and undulating hills and valleys abound in marls and sands of tertiary subapennine age, and that to the south the lowest member of these accumulations is charged with coal of miocene age, the upland tract now under consideration, and from which the boracic acid fumes issue, is chiefly composed of the rocks called Alberese and Macigno. The latter containing *Nummulites*, represents, in my opinion, the eocene, and the former be-

\* See Lyell’s Principles of Geology, 7th ed. p. 243.

† Quarterly Journal of the Geological Society, vol. i. p. 296.

‡ Ibid. vol. v. p. 276 *et seq.*

longs to the cretaceous system. Professor Pilla enumerates, indeed, cretaceous fossils found in these hills, whilst the still higher ridge on the east of the tract which terminates southwards in Monte Gerfalco, as well as the ridges of Monte Calvi and Campiglia on the west, are both of jurassic age, the *Ammonites Conybeari*, Sow. and *A. costatus*, Schlth. occurring in them.

All these sedimentary rocks, from the jurassic to those of the eocene group inclusive, have been penetrated, and for the most part much altered, by igneous or plutonic rocks, the greater number of which have a serpentinous character, their prevailing direction being equally N.W. and by N., S.E. and by S. Upon entering this elevated tract from the north, I found that its chief town, Pomarancia\*, was situated on a plateau of shelly, tufaceous, yellowish, sandy marlstone—in parts a travertine. This band clearly overlies the subapennine marls of the adjacent hills and valleys on the north, in which the rock salt and springs of Volterra occur, and is probably of the same age as the uppermost yellow marine ‘pauchina’ of Tuscany, or as the lacustrine deposit in the valley of the Elsa, to which I have alluded in a previous memoir †.

The rock is disposed in horizontal masses, and denuded into abrupt escarpments, which in the middle ages formed the natural defences of the old feudal town. This tertiary deposit occupies the tract between the picturesque heights of Rocca Sillana on the east, the hot springs of S. Michele on the west, and Monte Cerboli on the south, where rocks of serpentine and gabbro rise up through strata of whitish grey alberese limestone and some contiguous schists and sandstone. It is near the junction of the intrusive rocks of serpentine with the depositary strata, which are there much contorted and broken, that certain hot springs appear; four of which, at Monte Cerboli, have recently been made known and their contents analysed by Professor Targioni Tozzetti‡. His observations and analysis are of geological importance, inasmuch as they show that those springs which appear at intervals between Monte Cerboli (Mons Cerberus?) and Lardarello, where the vapours issue, define a line, as he says, from N. to S. (but accurately N. and by W., S. and by E.), and that essentially the springs contain, though in different proportions in each, the same ingredients as the lagoni or vapours to the south of them. Thus, exclusive of organic and bituminous

\* Pomarancia is the chief residence of Count Lardarel, the spirited and hospitable proprietor of the boracic acid establishments.

† Quart. Journ. Geol. Soc. Lond. vol. v. p. 294.

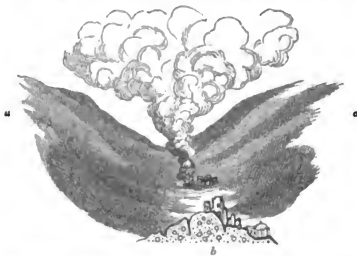
‡ Delle acque-termo minerali de Monte Cerboli. Firenze, 1846. Estratta della Gazzetta Toscana delle Scienze Medico-fisiche, An. 4. 2. 1. In this memoir the reader will find indications that the vapours of boracic acid had no issue in the beginning of the sixteenth century. See also notice of this tract by the early geological traveller Targioni Tozzetti (Viaggi), whose descendant, the living Professor of Chemistry in Florence, has also published analytical descriptions of the waters of Mont Alceto, Rapolano, Monte Catini, Castrocasa, Cimiano, and Casale.

Since writing the memoir I have been informed by Dr. Daubeny that the boracic acid vapours contain nitrogen gas—thus sustaining his views on the origin of volcanic action.

matter, all the wells contain chloride of sodium, carbonate of lime, the sulphates of lime, magnesia, and alumina, with boracic and siliceous acids. All of them are charged with carbonic acid gas, and one of them with a minute portion of sulphuric acid gas.

The spot now called Lardarello, where the new establishment has been built, is that portion of the valley rising from Monte Cerboli and watered by the Posera from whence the hot vapours escape by orifices, which, like the mineral springs, mark a line from N. and by W. to S. and by E. (fig. 1). The sides of this valley consist chiefly

Fig. 1. *Lardarello and the Soffioni seen from Monte Cerboli. Looking S. and by E., Lardarello buildings seen one mile off.*



*a. Alberese and macigno.*

*b. Gabbro rosso and serpentine.*

of alberese limestone and schists, with some points of protruding serpentinous rocks, the lower slopes being partially covered, as far as observation was possible, with younger marls. But whilst these rocks flank the fissure on the E. and W., it is quite open, as before said, to Monte Cerboli and its hot springs on the N. and by W. : it also leads through undulating ground to Bagni a Morbo, about a mile distant to the S. and by E., where hot mineral waters also exist. The present lagoni are artificially formed on those points where water and earth are applied to the escapes of the intensely hot vapours. Partially repressing the issue of heat, by throwing on earth and clay, and thus controlling the size of the orifices, human agency forms active mud volcanos, the number of which and their successive operations are regulated at pleasure. From the limited space in this valley of Lardarello so irrigated and operated upon, various columns of vapour are seen rising to different altitudes, at different degrees of intensity. This perforated ground is in a continually chaotic state from the countless changes it undergoes ; and its outlines are indeed so constantly varying by the formation of fresh outlets of gas, that the traveller who should venture among its mazes without an experienced guide would be exposed to great danger. Even the workmen occasionally lose a leg, and sometimes life, when they incautiously tread upon a covering of earth too thin to prevent their sinking into a hot abyss.

The orifice which I best examined was perfectly circular, about fifteen paces in diameter, and at the most active moment of ebullition. Throwing up large globules from its bubbling surface, the heated matter is ever making an effort to overflow the rim of the little crater\*. Wherever the subterranean vapour escapes from a crack more or less vertical, and which presents no impediment, the muddy liquid rapidly attains its maximum heat, which is so intense, that, as M. Lardarel, jun., informed me, no instrument had yet been made to measure accurately the maximum heat beneath the surface†. It is probable that no active volcano exhibits greater heat at any point where a test can be applied. Twenty-four hours of this process suffice to saturate the bubbling mixture with boracic acid, and the stuff is then run off into flat cisterns at a lower level. The fluid is there reduced to a third of its volume by evaporation, hastened by the hot vapour being conveyed in tubes beneath the salt pans, and thus saving the former cost of a great consumption of fuel. After the addition of soda, the desiccation proceeds, and crystals of boracic acid are formed. The violence with which the hot gas issues from any crack, provided it be vertical, is such, that if stones of some weight are thrown upon a narrow gush of it, they are heaved up several feet into the air, and heavy flagstones are required to repress the eruptive agent, and conduct a current of it down to the drying houses and pans.

It is highly interesting to compare the present issues of the hot gases and the forms of the lagoni, as arranged and controlled by man, with their natural appearance upwards of eighty years ago, when examined and described by Targioni Tozzetti. The thick white and hot sulphureous clouds rising by fits and starts,—the occasional jets of liquid rising from the boiling cauldrons,—the large and brilliant globules as they burst,—the circular shapes of the lagoni,—the incrustations of sulphur on their banks,—the crackling of the light, pumiceous and hollow ground under foot,—the conversion of the contiguous alberese limestone, then considered a primary rock, into a farinaceous or mealy state,—the fumes serving as a true barometer to the neighbourhood‡,—the perfect salubrity of the spot to animals, though plants are there withered and blasted;—all these phænomena are nearly the same now as when our predecessor described them. But, on the other hand, some of the former phænomena are no longer recognizable. There is no more a countless number of lagoni. We cannot now, as Targioni did, look into dry cavities from which hot blasts only issued, with noises as if from a hundred bellows, and distinguish them from those holes which were then naturally

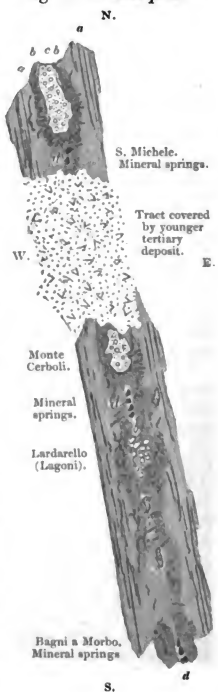
\* In his description of the Hawaii Islands of the Pacific, Mr. Dana accounts for the absence of active eruption and projection of materials into the atmosphere, by the great dimensions of the chief crater, in which the molten matter having a very wide vent, undulates with little or no noise, and quietly overflows its lip from time to time.

† Targioni Tozzetti, the old writer, does not pretend to have ascertained the extreme heat of the vapour; but Professor Pilla, on what authority I know not, places it at 140° Reaumur.

‡ In rainy weather, or when change is coming on, the vapours cling to the earth with increased subterranean noise, and in settled fine weather they rise to a great altitude.

filled with boiling muddy water, discharging gas; for the manufacturer now utilizes all the hot gas, and by the addition of water makes gaseous orifices into mud volcanos. Nor can we any longer recognize a hot lagoon approaching to the diameter of sixty *braccie*, which Targioni gives as the maximum size; still less have we a little island floating in such a hot lake. The noises and reverberations in the caverns, which he compared to the beating of a hundred fulling-mills, were doubtless much more overpowering formerly than now, when the apertures are so much closed in, and the issue so regulated. We learn, however, from the above-mentioned faithful historian two points of importance in the consideration of these forms of volcanic action:—1st. That although the lagoni were then said to be increasing in number, one of the orifices, at Monte Cerboli and another at Castel Nuovo, had ceased to act in his time. 2ndly. That flames were said to issue by night\*.

That a connection exists between the Soffioni and the former geological eruptive agency of Tuscany is apparent, the moment we collate the present and the former phænomena. The inference is indeed determined by an appeal to the very line under consideration (see fig. 2). Beginning at the north and by west, we see at S. Michele a copious outburst of serpentine and gabbro, and with it much contortion and rupture of the contiguous alberese limestone; and just at this junction, the hot springs of S. Michele, celebrated for many ages for their medicinal virtues, have their issue. Proceeding thence over undulating ground, for the most part occupied by tertiary tuff, we again find at Monte Cerboli (Mons Cerberus) on the S. and by E., a like conjunction of similar eruptive rocks and dislocated strata, and with them the issue of the before-mentioned hot-springs. Thenceforward to the S. and by E.,

Fig. 2. *Ground plan.*

- a, a. Alberese and macigno (cretaceous and eocene).  
 b, b. Altered alberese and macigno.  
 c. Gabbro rosso.  
 d. Thermal springs.  
 e. Lagoni or Soffioni.

\* Targioni Tozzetti quotes Ugolino da Monte Catini's description of the fumes at Castel Nuovo, near to the baths of Bagni a Morbo, and cites his omission of any allusion to those of Monte Cerboli as an indication that the latter have burnt out since that time.

the connection alluded to becomes much more interesting; for, as before said, four hot springs boil up *in the same linear direction*, and it is important to remark, that of these, the spring which is nearest to the lagoni partakes most of their boracic character. In short, the springs and the Soffioni charged with sulphuric, carbonic, and boracic acid, issue upon the very same line; and in following this line a little further to the S. and by E., we reach Bagni a Morbo, where hot sulphureous springs issue from fissures in rocks similar to those of S. Michele and Monte Cerboli. Still further to the S.S.E. the boracic acid fumes reappear in a remarkably picturesque cleft of the rocks of macigno, at Castel Nuovo, where the linear direction of the vents is very striking\*.

We have thus along a distance of about six or seven English miles from N. and by W. to S. and by E., the clearest possible evidence that the present hot springs and vapours issue upon a line of fissure, in the alberese and macigno formations, which was formed in very ancient times, *i. e.*, as I believe, between the eocene and miocene periods; the production of such fissure having been accompanied by the outburst of great bosses of serpentine and other plutonic rocks.

By extending this observation I perceived that the other "Soffioni" of this tract exist under similar conditions, showing either the actual outburst of hot springs and vapours along such line of former eruption, or the close parallelism of the two lines of phenomena. Thus, in my journey to the miocene coal tract of the Maremma before described†, I found the little town of Monte Rotondo to be built upon a junction of serpentine with the sedimentary strata it had traversed; and in looking from that spot to the N. and by W., I saw the vapours of the Soffioni, which bear the same name, issuing, like those of Lardarello, from a valley encased in flanking ridges of the same hard rocks. Again, the sulphureous lake, about two miles west of Monte Rotondo, having a major ellipse of north and south, is distinctly a prolongation of one of the numerous cracks extending thence to the N. and by W. towards Lustignano, by which boracic acid escapes.

In mentioning these "Soffioni," Professor Pilla‡ has specially described those of Sasso, and although he has not noted the coincidence on which I lay so much stress, any one who refers to his woodcut representing the issue at Sasso, will see that the line of vapour issuing from cavities is parallel to the main direction of the encasing ridges§. Now, these ridges of alberese and macigno have either a dominant direction from N. and by W. to S. and by E., or are perforated along such line by the serpentine, granitone (greenstone), or other eruptive rocks, including gabbro, to which I shall afterwards advert. Hence it appears, that the ancient lines along which nature expended some of her grandest energies in this region, are also those along which she still manifests the present escape of hot springs and

\* This is well described by Targioni Tozzetti.

† See Quart. Journ. Geol. Soc. vol. v. p. 292.

‡ Trattato di Geologia, p. 282. Pisa, 1847.

§ I cannot but express a hope that Mr. Babbage will at some time give to the public a copy of the suggestions he furnished to the Grand Duke of Tuscany, for the extension of the useful employment of these hot gases, which might thus serve to convert a barren tract into a wealthy manufacturing district.



gases. Again, these hot gases still produce, though on a small scale, those conversions or metamorphisms of the strata on the sides of their escape, which the geologist can well understand to have operated more largely and powerfully at that period when great masses of serpentine and other igneous rocks were evolved (or strove to be evolved) under enormous pressure, through the younger secondary and oldest tertiary deposits. At Lardarello, for example, small portions of the ordinary alberese limestone have been and are still converted into sulphate of lime by the action of sulphuric acid fumes; and the schistose calcareous shale is baked by the intense heat into brittle porcelain rock of a red colour. But I would here observe, that in these recent and partial metamorphoses by natural causes, as in those of ancient date, traces of the original lamination or stratification are nearly always perceptible in the lumps or masses so affected or altered.

*Gabbro Rosso.*—The last observation leads me to offer some remarks on the nature and origin of the "gabbro rosso" of the Tuscans; for after an attentive examination of this rock throughout the tract immediately to the north of the boracic acid country, I feel compelled to express my dissent from the opinion of Professor Paul Savi, in which my friend Mr. W. J. Hamilton in his description of the geology of Tuscany has coincided. The chief masses of "gabbro rosso" lie in the tract south of Pisa, and east and south-east of Leghorn, which is bounded on the north by the valley of the Arno, and on the south by that of the river Cecina. The varieties of this rock are instructively exhibited in the ridges of alberese and macigno, which form the east and west sides of a longitudinal depression occupied by subapennine marls, that extend from Colle Salvetti near the Pisan valley on the N. and by W., to the valley of the Cecina on the S. and by E. The direct road from Pisa to the Maremma is conducted along this depression. The westernmost of these ridges, which forms the bold coast, south of Leghorn, containing much granitone, serpentine, and other varieties of eruptive rock, also exhibits, particularly along its eastern face, a good deal of the "gabbro rosso," which, as Professor Pilla informed me, obtained this name from the village of "Gabbro," a few miles south-east of Leghorn, which is built on the summit of a conical hill composed of such rocks;—I say rocks called "gabbro," because it will be presently shown, that two rocks of entirely different origin have been united under this one name.

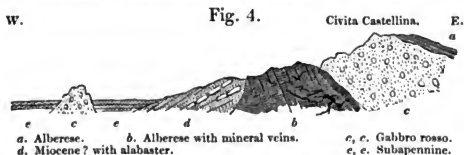
The eastern or inland ridge rises boldly up into the mountains which proceed from the north of Monte Vaso to Castellina Marittima on the south, and it is in reference to this group of hills, on the eastern part of which Monte Catini is situated, that I specially call attention, as it affords ample materials for settling the question which has arisen between Professor P. Savi and Mr. W. J. Hamilton on the one hand, and the late Professor Leopoldo Pilla and myself on the other. The two former have endeavoured to show, that whether in its globular and amorphous form, or in its thin-bedded state\*, the rocks they call "gabbro rosso" are metamorphic; whilst Professor Pilla

\* See Mr. Hamilton's translation of Savi's description, Quart. Journ. Geol. Soc. vol. i. p. 288.

and myself contend, that the amorphous, variolitic gabbro must have been erupted in a molten state, whether we consider its composition and unbedded condition, or the part it has played in protruding through, overturning, breaking, and altering the pre-existing strata. And although my deceased friend Pilla has to a certain extent published this opinion, he has not sufficiently illustrated his views, and I am therefore the more anxious to do him justice, and to adduce some of the reasons he assigned when we visited the tract together. The opinion of an attentive and lively observer of igneous action like Pilla, a Neapolitan by birth, who during many years was occupied in examining Vesuvius, is surely entitled to much consideration in determining such a question; even had not the physical and geological relations of the phenomenon seemed to me quite conclusive. Between Castel Anselmo and Civita Castellina I inspected natural sections, of one of which I here give a sketch (see fig. 3), where the gabbro had



not only penetrated the alberese limestone, but had thrown it off in shreds, contorted fragments, and folds on the sides of the eruption. Now, the red gabbro which had manifestly thus acted was entirely an unbedded, amorphous, felspathic mass, for the most part made up of spheroidal concretions having a variolitic structure, *i. e.* with small pustular or globular surfaces in each of the folds or concentric layers into which the large nodules exfoliate. This variolitic surface was specially pointed out to me by Pilla as a proof of the rock having been in complete fusion; inasmuch as the same forms occur frequently in ancient plutonic rocks and in the modern volcanic products of Vesuvius. The rock is, besides, often cellular and amygdaloidal as well as veined, like some of our earthy Scottish traps, occasionally containing crystals of carbonate of lime, analcime, and also the peculiar mineral caporcianite, a variety of stilbite. Chemically considered, this rock is little else than a variety of greenstone. In other words, it is one of those products, accompanying greenstone and serpentine, which has been much impregnated by iron, and which under the blowpipe melts as easily as wax. This is the "gabbro rosso," which I consider to be a true eruptive rock, and which rises up into an



amorphous mountain mass (c) at Civita Castellina, where it performs, as above mentioned, the part of an intrusive agent. It there throws off on its eastern summit the alberese limestone (a), but also seems to overlap other masses of the same (b) which are in a highly fractured and mineralized condition, as seen in fig. 4. From the natural section

here exhibited, it is certain that this eruption of "gabbro" took place after the consolidation of the alberese and macigno formations, *i. e.* after the younger chalk and older eocene. It is also further evident that another movement of elevation occurred after the miocene period; for not only is the limestone associated with white marls (*d*) to a great extent loaded with alabaster, which some persons might infer was altered limestone, but the whole of this mass has been considered to be miocene, simply because it dips away from the alberese and gabbro in inclined strata, and is thus placed in striking contrast with the subapennine or pliocene marls of the valley (*e*) which surround a boss of "gabbro rosso" in perfectly horizontal and unbroken layers. The altered alberese at Civita Castellina has here and there serpentinous soft bauds, and bears a metamorphic aspect, with a slickenside surface, accompanied by cracks and numerous veins of arragonite, all of which specially abound near the junction of the alberese with the "gabbro." Copper veins, however, either traverse the alberese or run down its junction with the gabbro; and are therefore of date posterior to the eruption of the latter. It is indeed the opinion of Pilla, that the copper veins have resulted from the same igneous action which evolved the "gabbro rosso," and are contemporaneous with that rock, whilst other authors contend that they are posterior to it. In traversing on foot the wild ridges which separate Civita Castellina from Monte Catini, where the richest copper ores abound, I witnessed repetitions of the chief phenomena above alluded to, in which, besides "gabbro rosso" and felspathic trap (the epidosite of Pilla), there were other rocks of this class both of greenish and purple colours, which I should class as greenstone and serpentine. All these amorphous masses, however diversified in aspect and structure, seemed to me to form parts of the same eruptive matter which has penetrated the macigno and alberese in lines from N.N.W. to S.S.E.

At Monte Catini, where Mr. Hamilton seems to have most studied it, the gabbro rosso appears in a bold promontory fronting the valley of the Cecina on the south, and Volterra on the east. The chief mass is here the same amorphous spheroidal variolite as in other places. Partially, indeed, it assumes still more a serpentinous appearance; the dull red globular lumps and spheroids being often enveloped in greenish coatings. It is not my province to allude to the splendid veinstones of copper\*, occasionally quartzose, which ramify along its edges or through this "gabbro." I content myself with saying, in reference to the point at issue, that in numerous galleries and cuttings the clearest proofs are exhibited of the homogeneity of structure of the amorphous gabbro, and of the total absence of anything in it like original aqueous deposit. In this respect it bears no resemblance to any other metamorphosed stratum which ever fell under my notice. The variolitic arrangement of the spheroids is very striking. On exfoliation they exhibit the pustules before alluded to on the external surface only of each concentric fold,

\* As a wayfaring geologist, I was most hospitably received at his villa by Mr. Sloane, the intelligent proprietor of the copper mines of Monte Catini. The ore is very peculiarly diffused and merits a special study.

and they fall to pieces exactly like "basalte en boule." But besides this rock, which is the "gabbro" proper, and plays the same part in relation to the sedimentary strata as the granitone and serpentine and other adjacent rocks of a similar origin, there is a rock also called "gabbro rosso" by Savi and Hamilton, which abounds on the eastern flank of Monte Catini and other places, which is not only totally dissimilar in composition and form from that which has been described, but which I admit is clearly a metamorphosed stratum.

This is a jaspified red and green calcareous schist, marked by numerous thin laminæ of deposit, which is evidently nothing more than the argillo-calcareous portion of the alberese or macigno formations, which happened to be contiguous to the true gabbro when the latter was erupted. For it is plain that the amorphous gabbro (as seen in a very clear natural section) has twisted back these finely laminated jaspideous strata upon themselves at a point of eruption, as seen in fig. 5.

That in perforating, bending back, indurating, and dislocating the schist, the intrusive matter should have communicated its colour, and to some extent its mineral composition,

Monte Catini.

Fig. 5.



a. Gabbro rosso. b. Altered red schist. c. Alberese.

to the argillaceous and calcareous strata thus affected by it, is nothing more than must be looked for, and is indeed frequently found to be the case under similar geological conditions. This appearance of transition, from what must be granted to be true altered sedimentary layers into the amorphous spheroidal "gabbro," has led Savi and Hamilton to think that the spheroidal red gabbro is simply a still more highly fused or altered accumulation of the same aqueous matrix. When, however, we recede from the immediate point of contact, we have not only very different forms in the matrices of the altered and the eruptive rocks, but an essential difference of composition and structure. Pilla has indeed cited instances just as notable of the conversion or metamorphosis of the strata by gabbro rosso, as by granitic, pyroxenic, and porphyritic rocks\*. One of those examples is seen in the spot called Botro del Ribuo near Serazzano, where the spheroidal "gabbro rosso" has thrown the strata of macigno into a vertical position, and has changed them into jaspers of blood-red colour, highly charged with silex and oxide of iron†.

If, indeed, the argument about transitions from the rock which has been the agent of alteration into the strata which are altered, be admitted, we must re-open elementary questions in the physics of geo-

\* In his 'Richezza Minerale della Toscana,' Pilla unites the "gabbro rosso" with the other ophiolitic or serpentine rocks, which having acted as partial centres of elevation and eruption, rise up as conical, elongated, and rugged mounts, detached from one another (p. 39). He describes the copper of Monte Catini as lying in a true vein, which has the peculiarity of being contemporaneous with the associated gabbro, both of which are posterior to the sedimentary strata (p. 40).

† Trattato di Geologia, Part I. p. 510.

logy which I supposed were long ago set at rest. We may in that way be led to abandon many conclusions at which we had arrived, in refuting the doctrine respecting certain rocks of Cornwall, Norway, and other tracts which were believed by some authors to prove transitions from granites to slates, and thus to indicate a common origin of these two classes of rock! If this method of reasoning be again entertained (as it seems to me it is by M. Savi), then many of the inferences which geologists have drawn concerning the posterior intrusion of granite and other igneous rocks amid depositary strata will be invalidated. For, although there are numerous examples of such phenomena, which no sceptic can assail, still there are frequent cases where it is impossible to define the precise limit between the erupted molten matter and the altered rock. It is indeed in the very nature of the phenomenon that such should happen, and the time of practical geologists can be better employed than in disputing upon such points. Some persons may indeed argue, that many varieties of traps and amygdaloids were to a great extent evolved from the melting of the pre-existing strata in the crust of the globe, and I am quite ready to admit that such may have been the case. But this admission by no means removes them from that class of true eruptive rocks which, in the eye of the geologist, have acted mechanically and chemically upon the strata they have penetrated; for even some of the lavas of Vesuvius may be, in great part, fused and melted materials, formerly accumulated as marine sediment, which have been transmuted by intense heat under pressure. The practical point, therefore, for which I contend is, that the amorphous and spheroidal "gabbro rosso" of the Tuscans is from its composition, and still more from the geological part it has played, a true plutonic and eruptive rock; whilst the red jaspified schists, which have been also termed "gabbro," are nothing more than sedimentary strata altered by the heat attending the eruption of the adjacent masses.

*Lines of former and present disturbance.*—As it is along the lines of eruption of the serpentines, greenstones, and gabbro, *i. e.* from N. and by W. to S. and by E., that nature has been repeatedly labouring to evolve heat in the west of Tuscany, so also have the secondary rocks been alineated and altered in this direction. It is on the same line that the granitic rocks of Piombino have subsequently uprisen, the average direction of the whole of the coast of this part of Italy being parallel to it\*.

Further, it is on this line that the various Soffioni or vapour volcanos issue, and that earthquakes still most affect the surface. Those who would wish fully to comprehend the phenomena attendant upon the earthquake which last agitated the west of Tuscany, and particularly the tracts south of Pisa, should consult the descriptions of Professors Savi and Pilla. In accompanying the latter from Pisa to Civita Castellina, and in thus passing from N.N.W. to S.S.E. along the depression in the subapennine marls, which lies between

\* Pareto, Pilla, and the Italian authors show that the granite of Piombino and Elba cuts through the serpentine.

the ridges above described as penetrated by serpentine, gabbro, and other eruptive rocks, I was struck with the fact, that the most powerful vibratory disturbance occurred in the low hills and hillocks of incoherent materials along this very line. The shocks from north to south being most powerful in this parallel of longitude, it was natural that they should produce the most disastrous effect in that portion of the tract where edifices were placed on slightly coherent marl that rises into hillocks void of lateral support. The buildings which rested on the adjacent harder rocks of alberese, gabbro, serpentine, and greenstone were comparatively unaffected, whilst those which stood on marl had fallen or were much shattered. It is further worthy of notice, that in the deepest denudations amongst the hillocks of marl, particularly near Lorenzana, where the earth opened into chasms, subterraneous waters which had been hitherto imprisoned rose suddenly to the surface; just as if artesian wells had been sunk, and that the overlying crust of a basin had been broken through. Spouting forth sand and mud, these jets of water so threw out solid contents, that when dried up they resembled so many molehills with radii; the centre or box of each wheel-shaped body being composed of concentrically laminated sands, marking the point at which the water issued. These appearances not only served to explain the origin of the larger muddy bosses of similar form, common in the incoherent subsoils of Calabria, which have been so frequently subject to great earthquakes, but may also be viewed as another link which connects the present small disturbances of the surface, with the former powerful subterranean energy proceeding from igneous and gaseous development we have been considering.

Thus, in reference to my preceding memoirs and in reasoning by analogy, we are led to infer, that the great evolution of molten matter in former or plutonic times, accompanied by so much heat and its gaseous attendants as to metamorphose whole mountain chains, was succeeded, as the bottoms of the sea rose, by a considerable diffusion of volcanic materials, chiefly of subaqueous origin, but in part subaërial; and that, finally, the lands assuming their present relations to the sea, the extension of molten matter has been confined to a very limited number of fissures or vents of eruption, many of which have become extinct with the lapse of time. A portion, however, of these eruptions in Europe is still in continuous activity, whether emitting solid matter, as at Stromboli, or hot springs and vapours, as in the Tuscan Soffioni; whilst another portion is intermittent, as viewed in the paroxysmal outpourings of Etna and Vesuvius, the occasional formation of small new cones and craters under the waters of the Mediterranean, and the fitful lines of earthquake shocks with their accompanying outbursts of water.

In viewing the intimate connexion between all these phenomena, and in looking to the powers of the Soffioni of Tuscany, we might perhaps infer, that if these gusts of heat were entirely repressed by closing up the orifices through which they now escape, earthquakes to some slight extent might be expected still more to prevail in the neighbourhood, until the expansive forces were liberated; just as the

most calamitous shocks in Sicily and Calabria have occurred when Etna has been most dormant. Putting aside this speculation, the hot vapours may unquestionably be viewed as the remains of a former igneous action, which I believe to have been incalculably more powerful, not only because it is on the same band or its subordinate parallels that the copious masses of plutonic rocks of this tract and the adjacent mineralized strata occur, but because this line is absolutely coincident with the axis of the Carrara and other marbles and their associated slates and crystalline rocks of the Apuan Alps. Now, as those lofty masses or western Apennines, together with their lower parallels in the Gulf of La Spezia, have been shown to be simply altered strata of jurassic age\* ; so in extending our observation in the same line further to the N. and by W., we find that serpentinous rocks have there, as in the Tuscan Maremma, burst through alberese and macigno and in much greater volume. In truth, the copious serpentines and their accompaniments in and around the territory of Genoa, have converted the cretaceous strata into rocks having all the appearance of palæozoic slates and flagstones. Other and posterior movements have there also affected, though for the most part mechanically, the contiguous conglomerates and sandstones of miocene age, which on the sides of the pass leading from Genoa to Alexandria occupy very highly inclined positions. The phenomena in the Genovesato and Piedmont, like those in the Tuscan Maremma†, indicate that such beds of the middle tertiary age, whether marine or freshwater, have been dislocated along those lines of disturbance, which at an antecedent period had been marked by the protrusion of the serpentinous rocks in a molten state. In other words, it was by the post-eocene eruption, that the great metamorphosis of the pre-existing strata was caused. A long period of comparative repose followed, one of the earliest operations of which was the accumulation of miocene conglomerates, for the most part made up of strata previously altered by the serpentine eruptions; as seen in the hills north of Genoa and Savona on the one hand, or in the Monferrato (Superga) on the other. Another powerful disturbance subsequently took place, when these miocene beds were thrown upon their edges, or were fractured and highly inclined along the same general lines of fissure, which had been marked by a more intensely igneous activity in the previous or serpentine period.

Although the phenomena chiefly treated of in this memoir have reference to a great band of disturbance proceeding on the whole from N.N.W. to S.S.E. along a length of about 100 miles and a breadth of about 25 miles, a glance at the geological map of Italy by Collegno, combined with my knowledge of the country, has led me to think, that whilst this line of eruption contains within itself minor parallels, there are other and divergent lines, along which similar strata have been affected by the same eruptive rocks. The country of North-western Italy, which comprehends the Genovesato and the

\* See Quart. Journ. Geol. Soc. vol. v. p. 266 *et seq.*

† See former Memoir and Section Quart. Journ. Geol. Soc. vol. v. p. 283 to 292.

north of Parma, seems to have been the grand centre of serpentine eruption, from whence such lines radiate, as marked by the protrusion at intervals of igneous rocks and the bands of metamorphosed strata which constitute the loftiest ridges of Italy (see fig. 6, p. 383). In this way, the serpentine bosses of the Apennines, between Bologna and Florence, that trend from N.W. to S.E.—i. e. from the region of chief eruption—though divergent from the line of the Apuan Alps, and Tuscan Maremma, are exactly coincident with the major axis of the Apennines or great back-bone of Italy, the culminating points of which, as at the Gran Sasso d'Italia, 9530 feet above the sea, are composed of eocene (nummulitic) and cretaceous rocks reposing on jurassic.

Again, if we turn from the east and look to the other great band of eruption to the west of the coast of Italy, as marked by serpentines protruding through the cretaceous and eocene deposits of Corsica, we see (as graphically laid down by Pareto\*) that it marks nearly a meridian line. Looking then at Italy on the great scale, the geologist may, I think, satisfactorily connect its dominant physical features with former causes of upheaval. He sees that, as it is in the highly convulsed and broken-up region where the Apennines bend round to become confluent with the Alps, the greatest masses of serpentine have been emitted, so, exploring southwards from this grand focus, he observes that *bands of the same molten matter have been intruded into divergent cracks and fissures* in the crust of the earth, and extend in long linear directions to the S.E., S.S.E., and S. Geological investigation establishes, indeed, not only this fact, but also the important point, that such igneous matter was simultaneously emitted; since it has alone broken through and metamorphosed sedimentary strata of the same age through several degrees of latitude. Now, as few parts of Italy contain strata of higher antiquity than liasso-jurassic, and as there is no evidence that its submarine accumulations had ever been raised into dry land before the cretaceous and nummulitic rocks were accumulated upon them, we have a fair right to infer, that the linear eruptions of serpentine and their accompaniments of gas and heat, absolutely furnished the Peninsula with those chains of hard and altered strata (each containing subordinate parallels) whose features and contents have been described on a previous occasion. In short, there is no reason to believe, that Italy had any well-defined terrestrial existence until the period of the post-eocene serpentinous eruptions. As Corsica, however, is only the northern prolongation of Sardinia which contains Silurian fossils, and as both islands are characterized by a meridian chain of ancient crystalline rocks, it is clear that a very ancient mass of land ranged in that direction, as further proved by its old cry-

\* The reader who wishes to become acquainted with the various lithological characters of the rocks classed under the head of Serpentine, and which were all emitted at the post-nummulitic period, must consult the works of Pareto on Liguria Marittima, and on Corsica, both illustrated by excellent geological maps. Although the Marquis Pareto, following preceding authorities, has classed the nummulite limestone with the chalk, I trust he will now agree with me.



stalline and Silurian rocks being overlaid by palæozoic coal plants and a coal formation\*. It is certain, therefore, that the serpentinous eruption there found its issue along a line of fracture coincident with the north and south direction which had been impressed upon these lands at a very remote period—such eruption, though divergent from them, being simultaneous with the chief axes of upheaval in Italy.

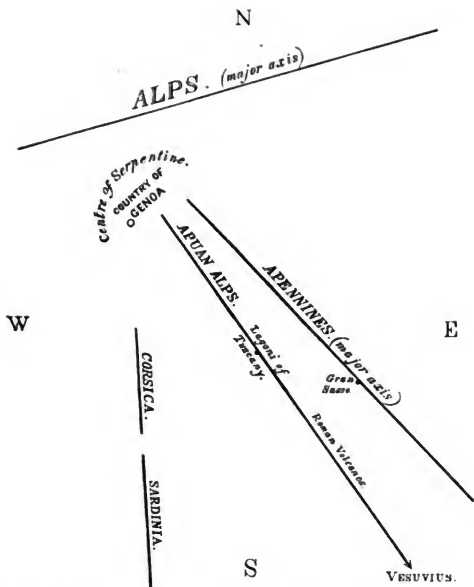
In speaking of divergent lines of fracture and elevation, which offer proofs of simultaneous eruption and dislocation, I am led to terminate my communications on the Alps and Apennines, by calling attention to the great phenomena which are common to these two chains and at the same time distinguish them. To render my idea clear I have annexed the accompanying diagram, fig. 6. Whilst the direction of the chief ridges of Italy is more or less at right angles to the main direction of the Alps, we know that the greatest amount of metamorphism has been impressed on both chains after the nummulitic period; and again, that in both very violent movements took place after the deposition of the miocene tertiary. In the chief

\* After this memoir was read, Professor Meneghini of Pisa communicated to me, that Professor Savi and himself had discovered undoubted species of coal plants (*Pecopteris arborescens* and *Annularia longifolia*) in anthracite schists, which on the right bank of the Era near Volterra form the lower part of the "Verrucano," or oldest conglomerate of Italy. A communication to this effect, on the part of his colleagues, was at the same time made by Professor Parlatore at the late Meeting of the British Association at Edinburgh. This important discovery seems to prove that a lower portion of the rocks called verrucano, which have hitherto been considered to be the natural base of the lias, is of the same palæozoic age as the conglomerates of the Valorsine and other places in the Alps. Yet still, in reference to my opinion above expressed, the plants found in Tuscany may either have been derived from lands now submerged, or from adjacent shores, of which the Silurian and ancient crystalline rocks of Sardinia and Corsica are the existing remnants. At all events, no rocks have yet been made known to geologists in Northern or Central Italy which are of sufficient antiquity to have been the *dry land* whereon the coal plants grew, to which Professors Meneghini and Savi have drawn attention.

As Italy is thus connected still more closely with the Alps by the feature of anthracitic coal plants common to both countries, I would here allude to an able recent memoir of Professor Heer (*Mittheilungen der Natur. Gesellschaft. in Zurich*, 1850), in which, specially referring to the case of Petit Cœur in Savoy, he argues, that the plants found there being terrestrial and of the carboniferous era, the stratum in which they are imbedded cannot be united with that which contains marine liassic belemnites. The general analogical reasoning of this author is so much in unison with my wishes, as expressed in the Memoir on the Alps, Apennines, and Carpathians (*Journ. Geol. Soc. Lond.* vol. v. pp. 176, 177), that I have only to regret he should have omitted to acquaint his readers, that I drew my inferences solely from the *actual section and the order and position of the beds*. I clearly stated that I did so in opposition to my desire to find the plants and belemnites lying in what might be considered separate formations. With the utmost deference to the value of organic remains, I felt however bound to affirm, that in the example of Petit Cœur, the *physical evidences* seemed fairly to sustain the views of M. Elie de Beaumont and M. Sismonda. At the same time, I did not deny the possibility (though as yet unexplained by an actual appeal to facts) of accounting for this singular collocation by an extremely sharp, inverted curvature, followed of course by powerful denudation. Lastly, I would now observe, that the naturalists who are most opposed to the views of MM. De Beaumont and Sismonda have not visited the locality, which they really must do before they can explain away by fair demonstration what they consider to be an anomaly.

range of the Swiss and Austrian Alps, the greatest changes of metamorphism, elevation, depression, and contortion have been determined upon lines having on the whole an east-north-east and west-south-west direction; whilst in the Apennines the same changes have occurred at the same periods on linear bands trending generally from N.W. to S.E., and even veering round to a meridian strike as they approach the direction of the ancient and palæozoic rocks of Corsica and Sardinia. Notwithstanding, however, their great diversity of direction, the Alpine and the Sardinian lines of active disturbance have

Fig. 6.



each been manifested along primæval coasts, the strata formed upon which contain palæozoic fossils. When, however, we pass from the consideration of events so long past to the contemplation of those agents of terrestrial change which have been most active in comparatively recent times, the Apennines are at once distinguished from the Alps in possessing those truly volcanic phenomena which connect geology and existing history. With the most frequent evi-

dences of recent mutations to an enormous extent in their outlines—*i. e.* since the period of the glacial waters \*—the Alps present nowhere the trace of any subaërial volcano; the youngest igneous rocks being those which have traversed the older tertiary deposits of the Vicentin and other tracts. The Apennines, on the contrary, offer proofs, particularly on their western shores, not only of recent oscillations, but also of copious volcanic eruptions. Thus, as was recently shown, subaqueous volcanos were intensely active during the penultimate period, along a band parallel to and flanking the Apennines, which had been raised at a former epoch. After these fires were spent and their dejections raised up into the western lands of the Papal and Neapolitan States, we have no proofs of subaërial volcanicity until Vesuvius burst forth, save the case of the volcano of Latium †, whose period of activity is lost in the maze of time, and the notable examples among the early Greek settlements in the Bay of Naples.

Lastly, let us recollect, that in the tract of Western Tuscany which has been the special subject of this memoir, we also read a most instructive lesson upon the efforts of *subterranean igneous forces to develope themselves at successive periods along one and the same established band of active change in the crust of the globe*. For whilst one extremity of this band is marked by the eruptions of Ischia and Vesuvius, where volcanic action has prevailed in the historical period, we have only to follow such zone from Naples to the N.N.W. to see that it passes along a portion of the Papal States replete with earlier volcanos, and is directly coincident with tracts powerfully affected in much more remote periods, along one of which volcanic action is still partially developed in the hot vapour issues of the Tuscan Maremma.

\* See "Distribution of the Superficial Detritus of the Alps, as compared with that of Northern Europe." (Quart. Journ. Geol. Soc. vol. vi. p. 65.)

† Quart. Journ. Geol. Soc. vol. vi. p. 294.

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